Fracturing, physical properties and flow patterns in isolated carbonate platforms

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Summary

A carbonate platform is a sedimentary system that represents a complex interplay between geological and biological processes during its development. The result of such interaction generally evident from the distinctive overall 3D geometry of the platform, lateral variations in lithological properties and unique stratification patterns in different parts of the platform body. Due to the reactive behavior of the platform, the chemical and physical properties of its constituent rocks are subjected to extensive alteration due to diagenesis processes. In many cases, major alterations are often related to sea water circulation or hydrothermal fluids that actively changing the material properties inside the platform during the deposition and/or throughout the burial history. As a result, the material properties inside the platform body are expected to vary significantly, both in horizontal and vertical directions.

Despite their complex nature, carbonate rocks are known to have an important economic aspect. In general carbonate rocks form major reservoirs for groundwater and hydrocarbon deposits. It is estimated that more than 50 % of the worldwide hydrocarbon reserves are contained within the carbonate reservoirs. Extracting important commodities like hydrocarbon from such a heterogeneous geologic body is technically challenging. The porosity and permeability in the carbonate reservoirs are expected to vary considerably, both vertically and laterally, influenced by the lithology and diagenesis. In addition, fractures are common due to the brittle behavior of carbonate rocks which could impact the fluid-flow behaviors in the reservoir. Typical for subsurface reservoirs, observations are mostly limited to small wellbore data and / or seismic images. For carbonate reservoirs, such a technical challenge results in a poor characterization of reservoir conditions. In general, wellbore data cover only a small portion of the reservoir and clearly not sufficient to capture the reservoir-scale heterogeneity, including the fractures. Such limitations will surely introduce some uncertainties in estimating the reservoir productivity and its economics. In contrast to the subsurface condition, outcrops provide excellent exposure and accessibility to rocks that are similar to those in the subsurface reservoirs. Extracting information from the outcropping analogues is clearly useful for subsurface reservoir characterizations.

By using outcrop observations as the base for discussions, this thesis aimed to provide a detailed investigation on the characteristics of distributed fractures and their impact on flows. This thesis focused more on the phenomena that take place inside an isolated carbonate platform setting. In contrast to a carbonate ramp, the isolated carbonate platform is characterized by a steeply dipping slope and a distinctive overall 3D geometry. In this study, the Latemar platform (Dolomites, Italy) has been chosen as the outcrop analogue for reservoirs with a similar setting. In performing the analysis, various analytical techniques have been implemented as one integrated workflow. The outcrop analogue was firstly used as the natural labora-

tory for fracture characterizations. Fractures from various locations in the Latemar mountain were then compiled and analyzed to investigate the role of various geologic parameters in controlling fracture patterns and distributions. To complement the outcrop study, a series of numerical modeling in geomechanics was then conducted separately. The numerical analysis focused more on the role of external stresses and mechanical properties in governing the reservoir-scale deformation. Results from both outcrop analysis and numerical modeling were then used to constrain a simplified carbonate platform 3D model for fluid-flow simulations. Here, the impacts that fracture network characteristics have on flow behaviors were investigated through systematic fracture modeling and numerical studies in dual-porosity/permeability fluid flow simulations.

Fracture analysis in the Latemar platform was conducted with two different approaches. First, fractures were measured directly from outcrop surfaces. The acquisition was done by implemented a new technique that enables a complete 2D description of fracture distribution (Chapter 2). Various statistical methods have then been applied to quantify the overall fracture patterns. More importantly, the investigation focused on understanding the geologic controls on fracture population and characteristics. The results indicate that fracture characteristics in the Latemar platform are highly influenced by first order sedimentological domains. Fractures in the massive slope and platform margin are generally larger and spaced much wider than those in the well-stratified platform interior. Stratifications and sedimentary layers, however, have less control on fracture terminations and fractures are mostly arranged in a unit, not confined within the sedimentary beds. The resulting analysis also indicates a temporal change in platform-scale mechanical behavior. Fractures are observed to increase both in size and spacing through time. Such a change in fracture geometry is interpreted due to the progressive lithification during burial. In the second approach on fracture analysis, larger structural features or fracture corridors have been interpreted from a 3D model or LiDAR that covers the entire Latemar platform (Chapter 3). Such a large-scale observation will complement the outcrop-based analysis, producing a multiscale picture of fracture patterns in the Latemar platform. From the LiDAR, the geometric characteristics of fracture corridors are extracted and linked with other geological observations to investigate their origin and the tectonic background of the Latemar platform.

Fracture observations from the outcrops are useful to extract detailed information on fractures geometries and their spatial characteristics. Fracture distributions throughout the carbonate platform, however, are best estimated from numerical modeling in geomechanics. For this purpose, the overall 3D geometry of the Latemar platform has been used as the reference for the numerical study (Chapter 4). The geomechanical analysis was done by implementing the finite element method (FEM) in investigating platform-scale deformation. Various mechanical scenarios have been conducted to mimic a burial process, with increasing overburden, of a carbonate platform down to its maximum burial depth. Different external stresses were also implemented in the loading scenarios. The analysis was focused to compare the stress/strain distributions due to a gravity-driven subsidence with those under the influence of horizontal tectonic stress. Various mechanical compositions were also considered during the analysis. Differences in mechanical properties were implemented to account for complex diagenetic processes that actively alter the bulk mechanical properties of domains in the platform, i.e. slope, margin and platform interior. The overall results were then summarized into three different aspects that mainly govern the fracture characteristics in the reservoir body, i.e. the orientation of principal stresses, distribution of fractured volume and the type of fractures (open or shear). By comparing the results from the numerical analysis with fracture characteristics in the Latemar platform, stress loading and mechanical compositions during fracturing in the Latemar platform can be inferred.

The impacts that fractures have on fluid flow are then discussed in Chapter 5. The overall analysis in this chapter was the implementation of an alternative workflow in modeling and upscaling the fracture network, especially for a reservoir-scale model. The need for such a workflow is mainly due to the technical limitations that requires massive computing power in fracture realization and upscaling. In common practice, fracture characteristics are often simplified and the roles of geologic parameters in controlling the fracture population are neglected. For this purpose, results from the fracture study in the Latemar platform (Chapter 2) have been used to base the overall analysis. Fracture modeling was then conducted at a sector scale instead of a reservoir-scale model. Each sector was defined as a part of the reservoir that exhibit similar fracture characteristics. The effectivity of such a small model enables a multiple realizations and upscaling processes, which is important to account for various sensitivity analysis and unconstrained parameters. The upscaling results were then used to populate a reservoir model for dual-porosity/permeability fluid flow simulations. From the fracture modeling, it is clear that differences in fracture network characteristics will partition the flow behaviors inside the reservoir body. Fluid-flow simulations indicate major differences in flow patterns and reservoir productivity that are largely related to changes in fracture network characteristics.